Centre for Medical Radiation Physics

University of Wollongong

Out-Of-Field Dose Equivalents Delivered by Passively Scattered Therapeutic Proton Beams

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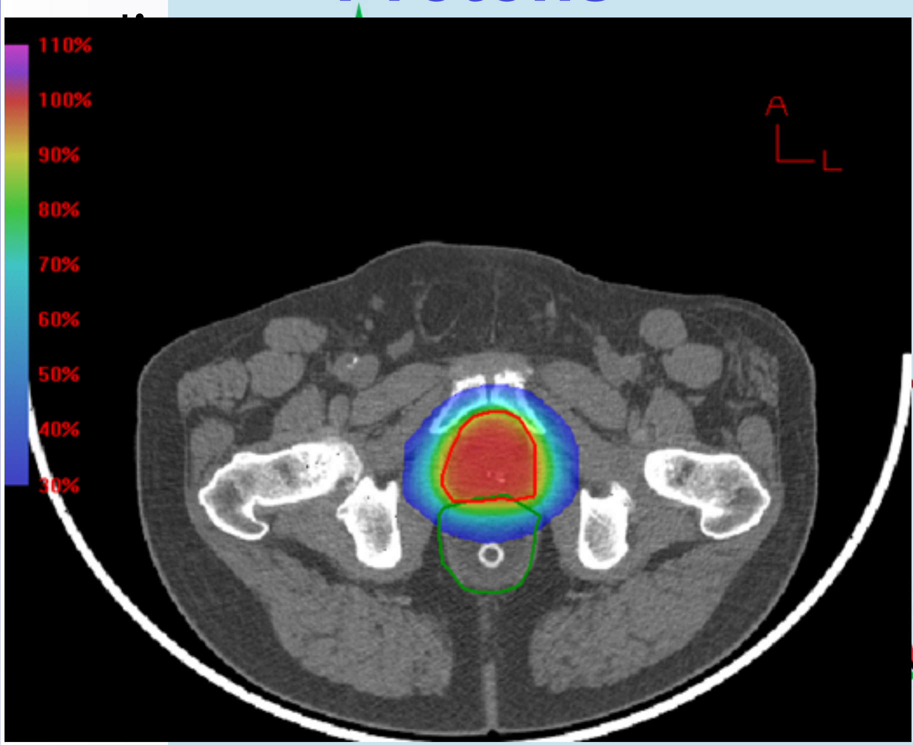
Background

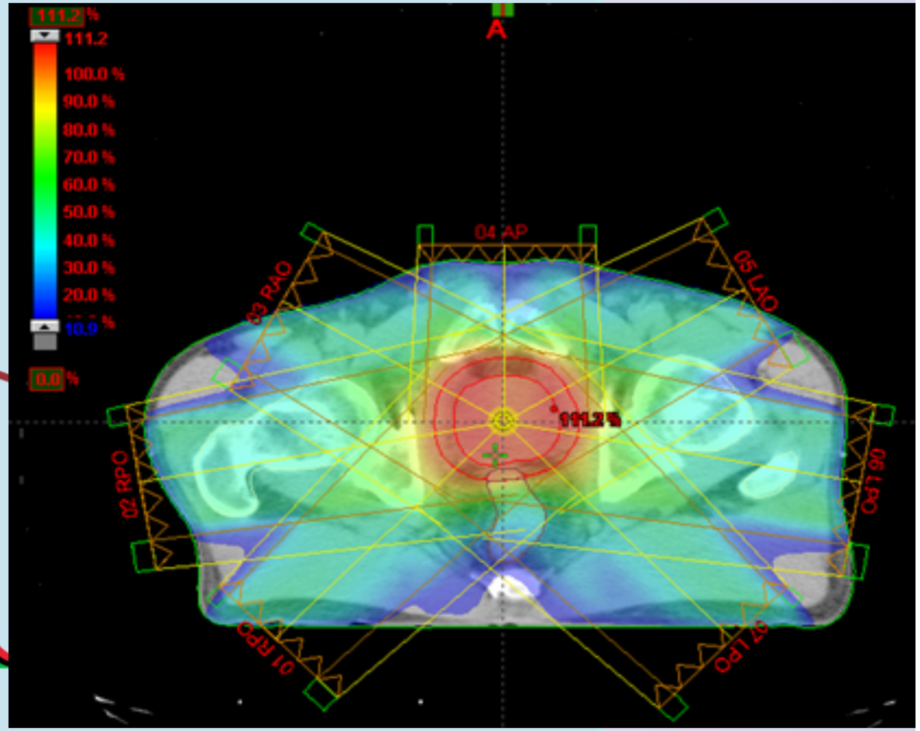
- Protons are a useful tool for cancer treatment
- The … dose

Proton depth-dose distribution

Protons

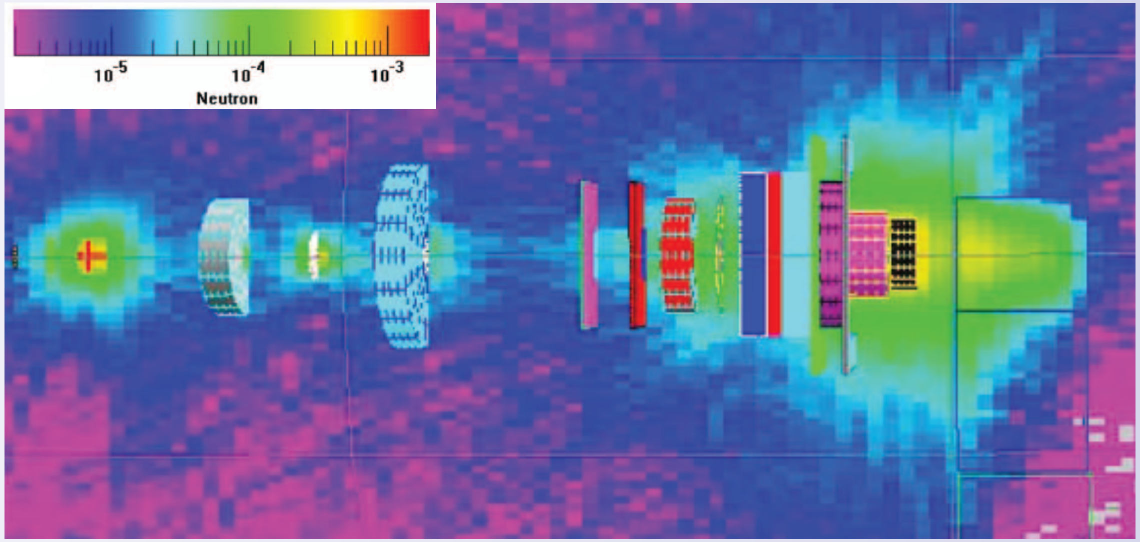


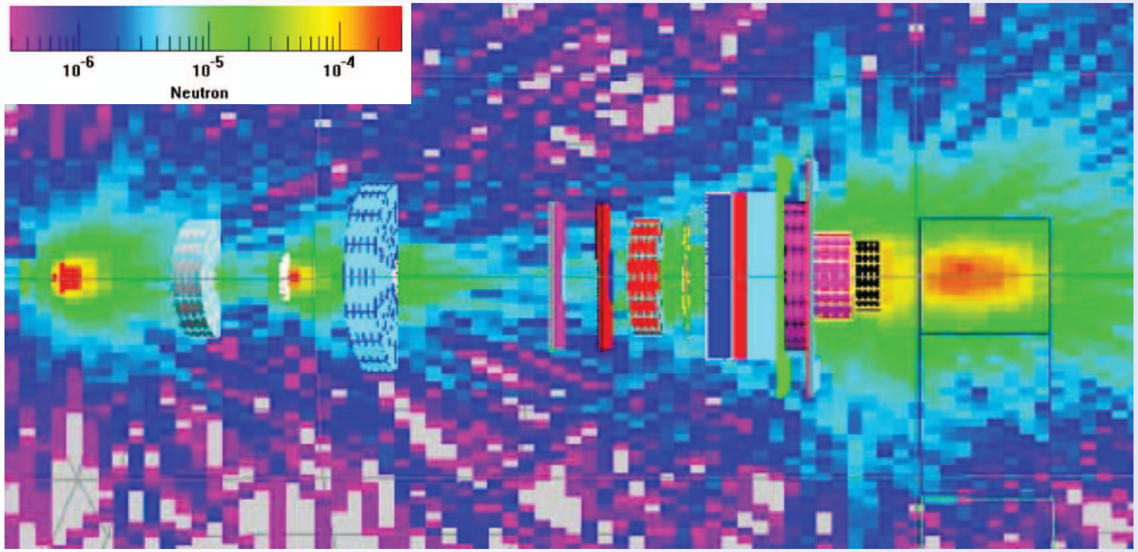
IMRT



Neutron Production

Neutrons with E<10MeV →





← Neutrons with E>10MeV

[1] M. Moyers et al., "Leakage and scatter radiation from a double scattering based proton beamline", Med. Phys., 35, 1, 2008, pp. 128-144

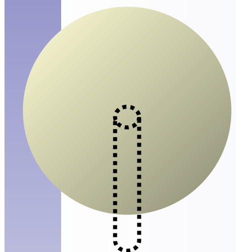
Dose Equivalent Measurements

- Physical measurements in such cases are scarce
- Detection of a range of particles is required
- High spatial resolution is required for measurements within phantoms in close proximity to the field edge
- Consideration of mixed particle quality factor for the determination of dose equivalent is also difficult
- Clinically relevant measurements are required
- Measurements are necessary to validate Monte Carlo

Equipments

- Bonner sphere

LUDLUM neutron ball cart model 42-5
(diameter: bare, 2”, 3”, 5”, 8”, 12”)



detector:
LiI(Eu) scintillator, 4mm x 4mm

$$^{6}Li + n_{th} \rightarrow \alpha + ^{3}H \quad Q=4.79MeV$$

Courtesy of Dr Matsufuji, HIMAC

- rem counter

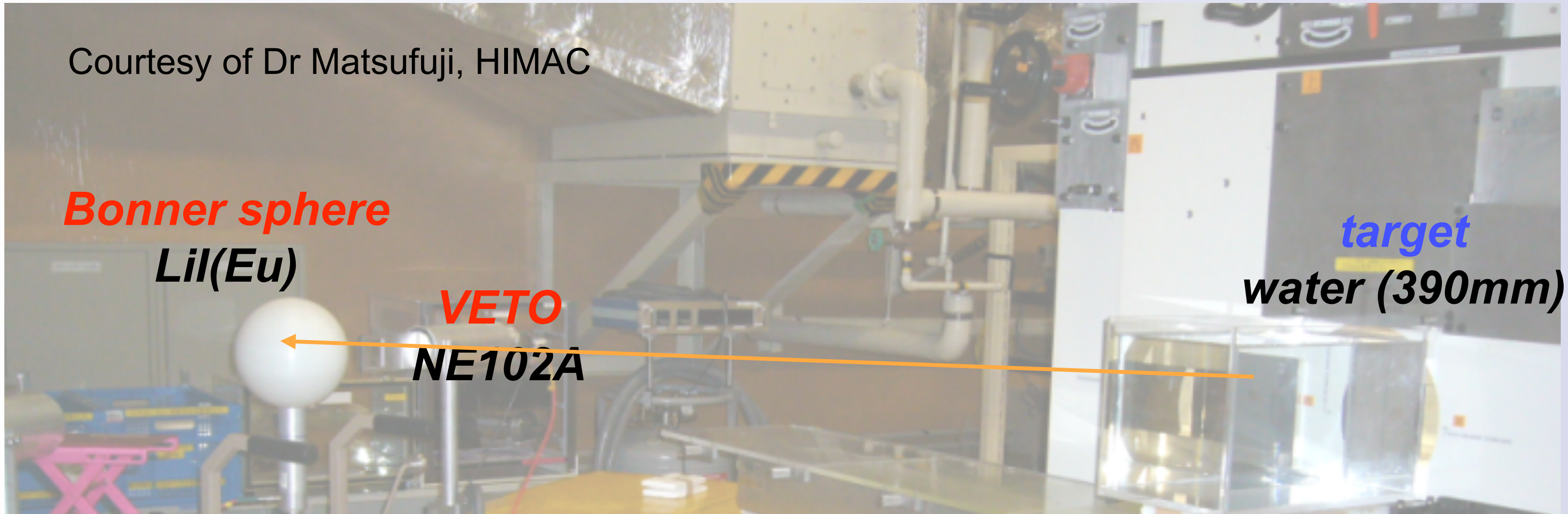
ALOKA neutron survey meter TPS-451C

detector:
^{3}He proportional counter

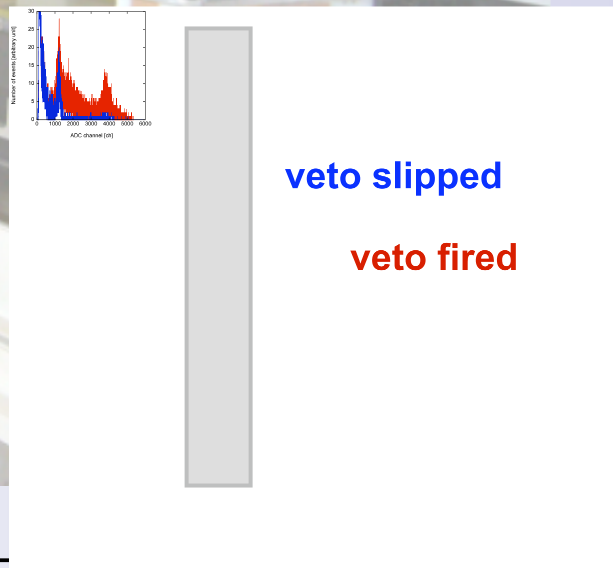
$$^{3}He + n_{th} \rightarrow ^{1}H + ^{3}H \quad Q=0.77MeV$$

- Sv (up to 15 MeV)
- energy spectra not available

Experiment (HIMAC, BIO beam line)



- incident beam (~160mm range in water)
  - ^{12}C-290MeV/n, ^{1}H-160MeV
  - 100mm dia., SOBP 60mm
- target
  - water (390mm)
- position
  - 0, 15, 30, 45, 60, 90 deg
  - 173 cm from target

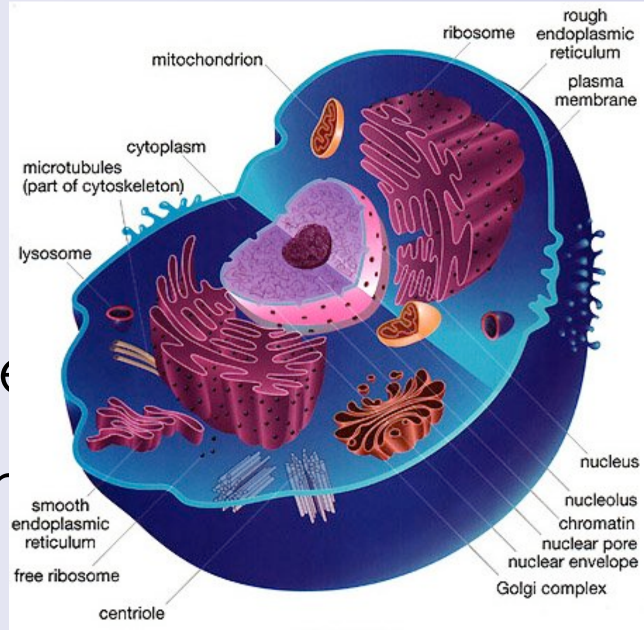


Research Aim

To conduct microdosimetry measurements of external field dose equivalents for passively delivered clinical treatment fields in proton therapy

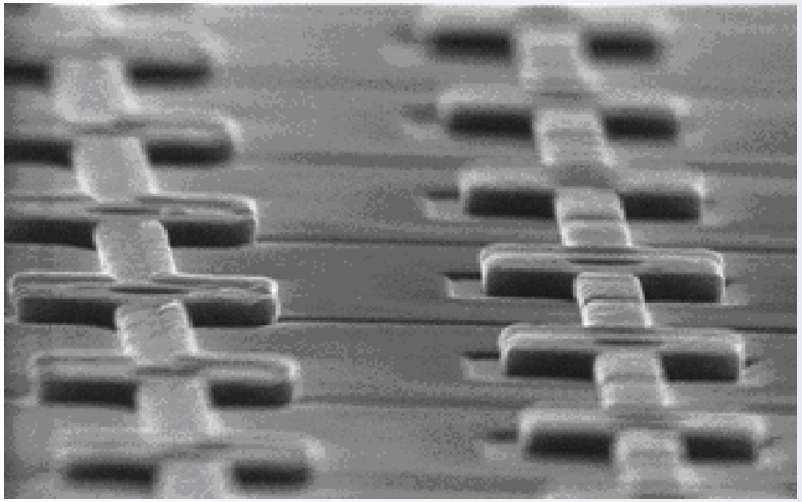
What is Microdosimetry

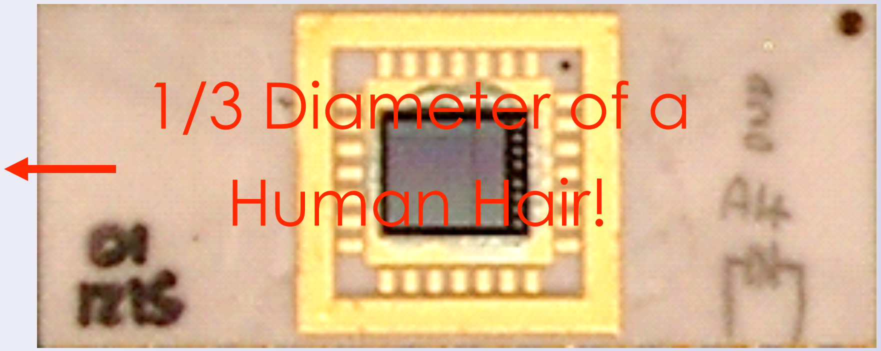
- When measuring cellular effects, it makes sense to use detectors the same size as a cell - **MICRODOSIMETRY**
- Size = 10μm = 1/2500 inches
- Each event interacting with the volume is measured and recorded
- Suitable for measuring neutron dose
- "Dose Equivalent" can be determin



Solid State Microdosimetry

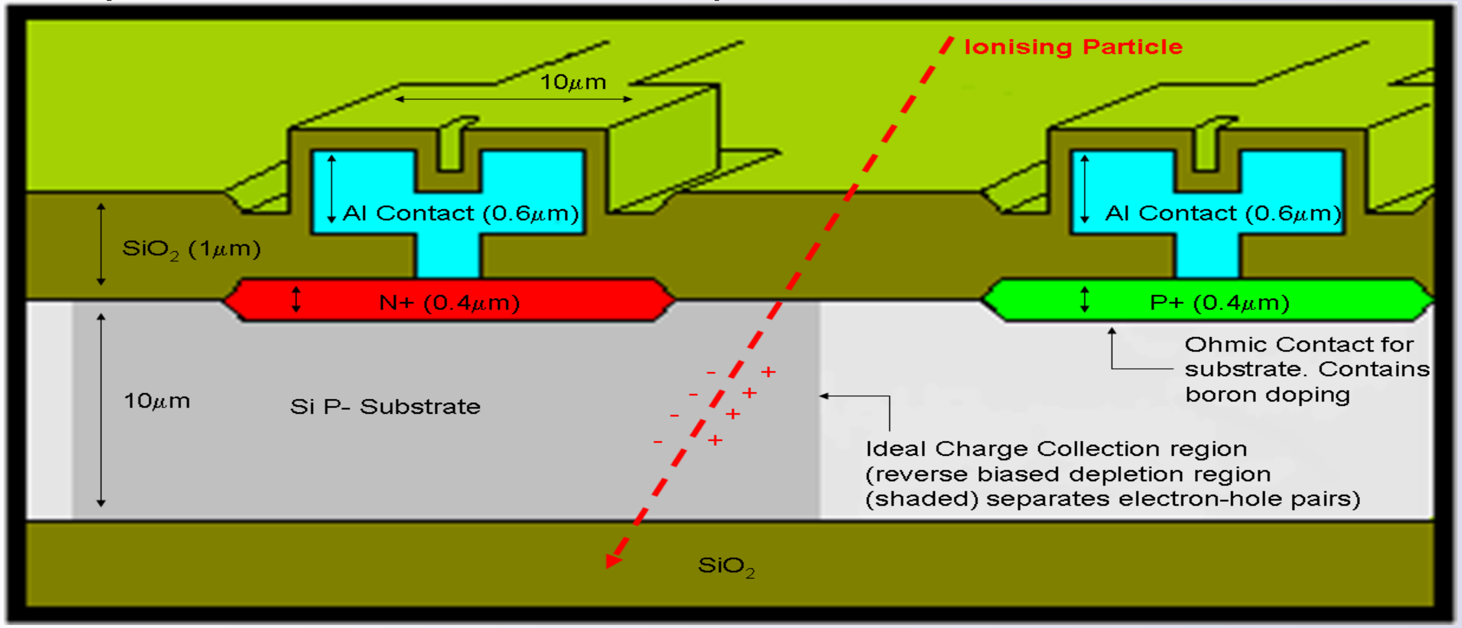
- SOI microdosimeters developed by Centre for Medical Radiation Physics at the University of Wollongong
- Small size allows for accurate measurements near the treatment field edge
- Tested extensively in Proton and Heavy Ion Therapy



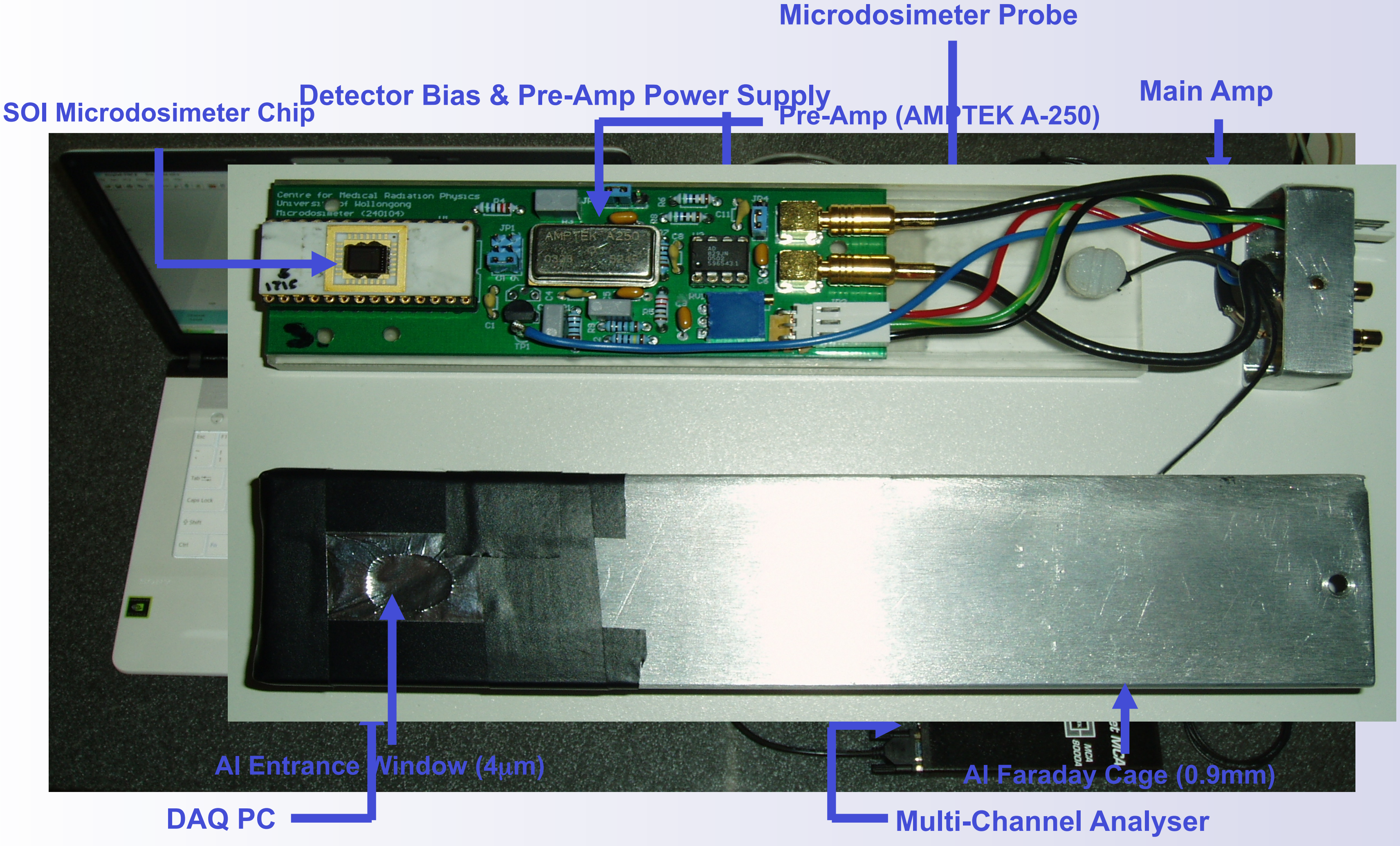


Silicon-On-Insulator (SOI) Microdosimeter

- Provides true microscopic Sensitive Volumes
- Volume Area 30x30μm^2 or 100x100μm^2
- Volume thickness either 2, 5 or 10μm
- Array size 50 – 5000 independent cells

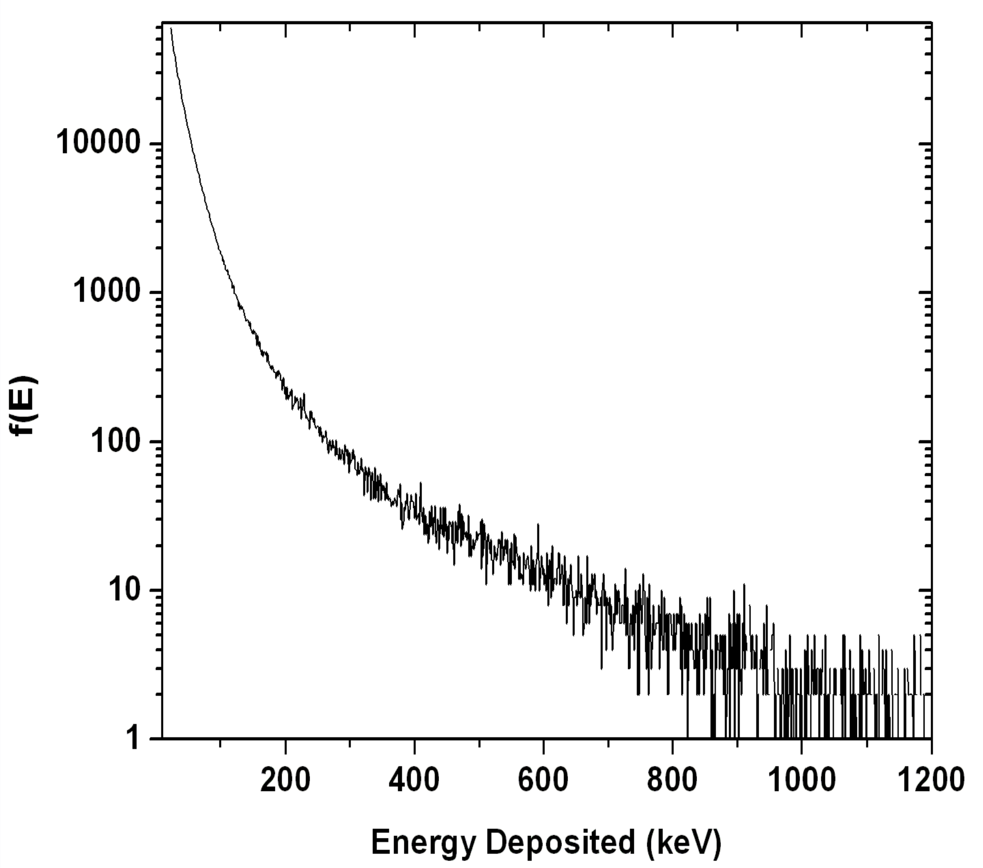


Experimental Setup



Dose Equivalent Determination

- Dose is determined from the f(E)/E Spectra in the following method:

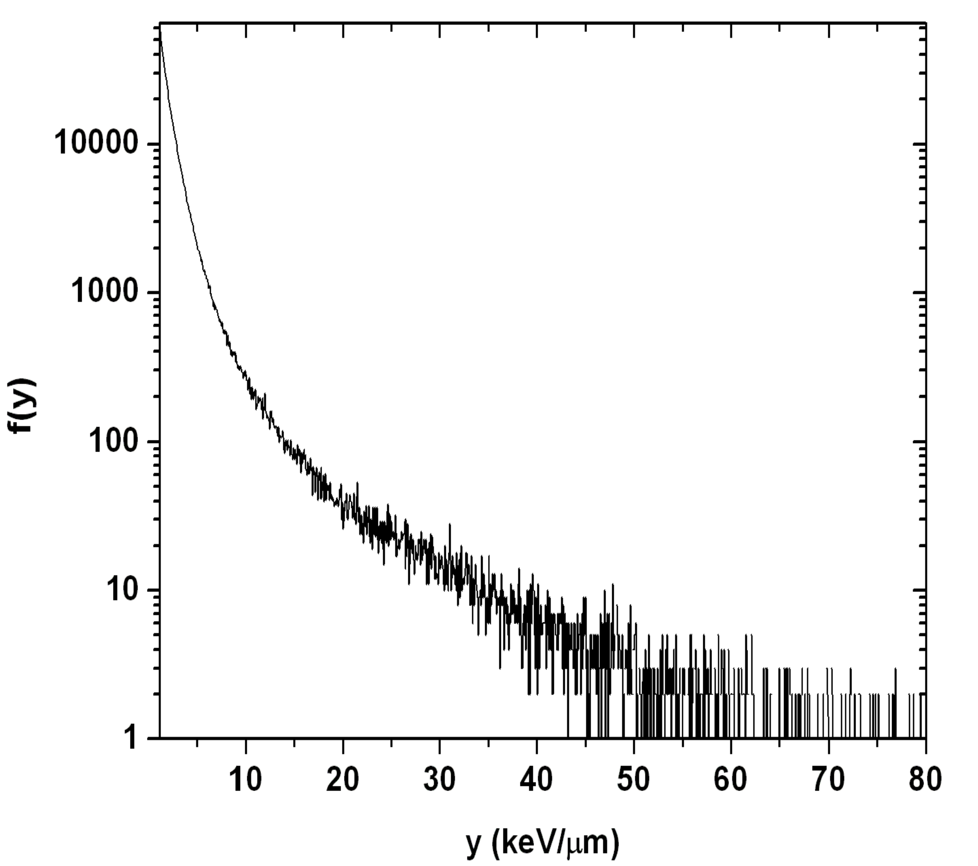


$$D_{Si} = \frac{\int_0^\infty f(E).E.dE}{M} = \frac{\int_0^\infty f(E).E.dE}{\rho_{Si} V n_{cells}}$$

$$\therefore D_{Si} = D_{TE} \frac{S_{Si}}{S_{TE}}$$

Dose Equivalent Determination

- The lineal Energy Spectra is determined by dividing the energy by the mean chord length <l>:



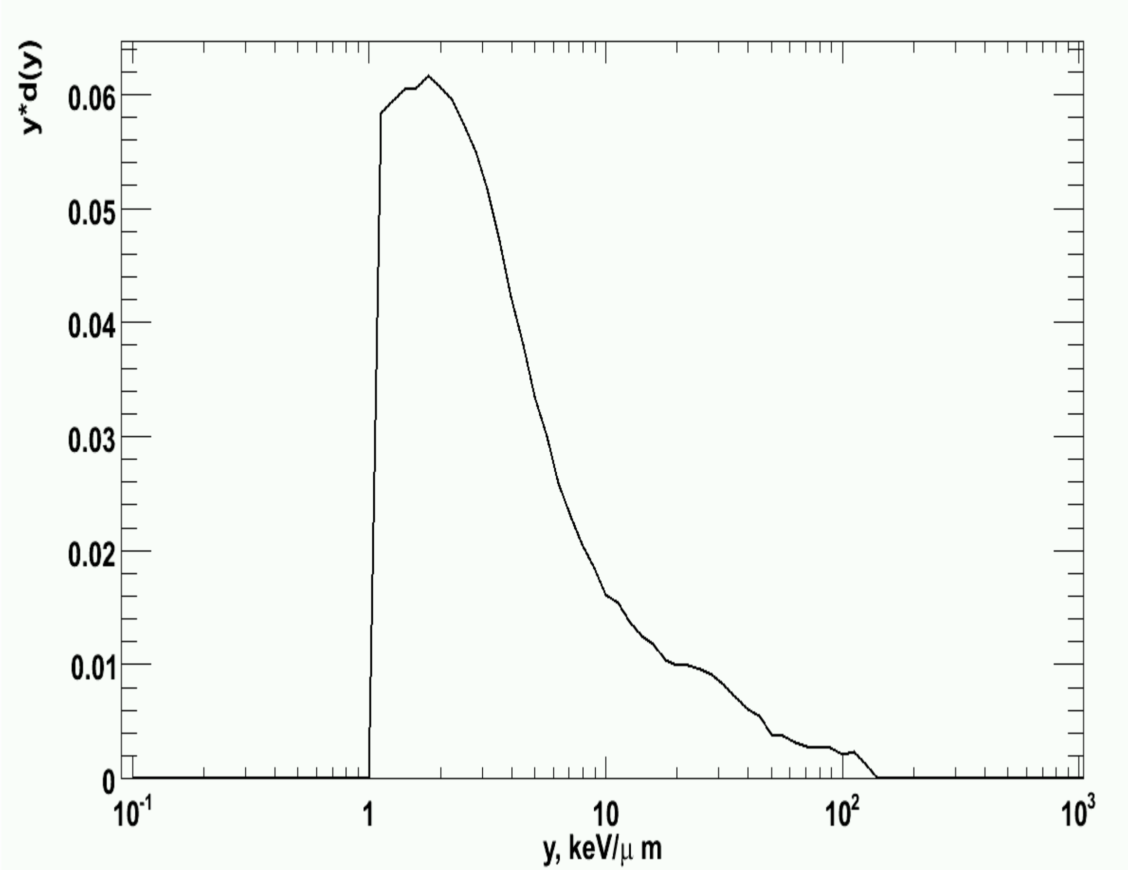
$$< l > = \frac{4V}{S\zeta}$$

$$y = \frac{E}{< l >}$$

- Where <l> in this case is 19.05μm and ζ=0.63 is the TE conversion factor

Dose Equivalent Determination

- A normalised dose weighted lineal energy spectra can be obtained using the following relationship:



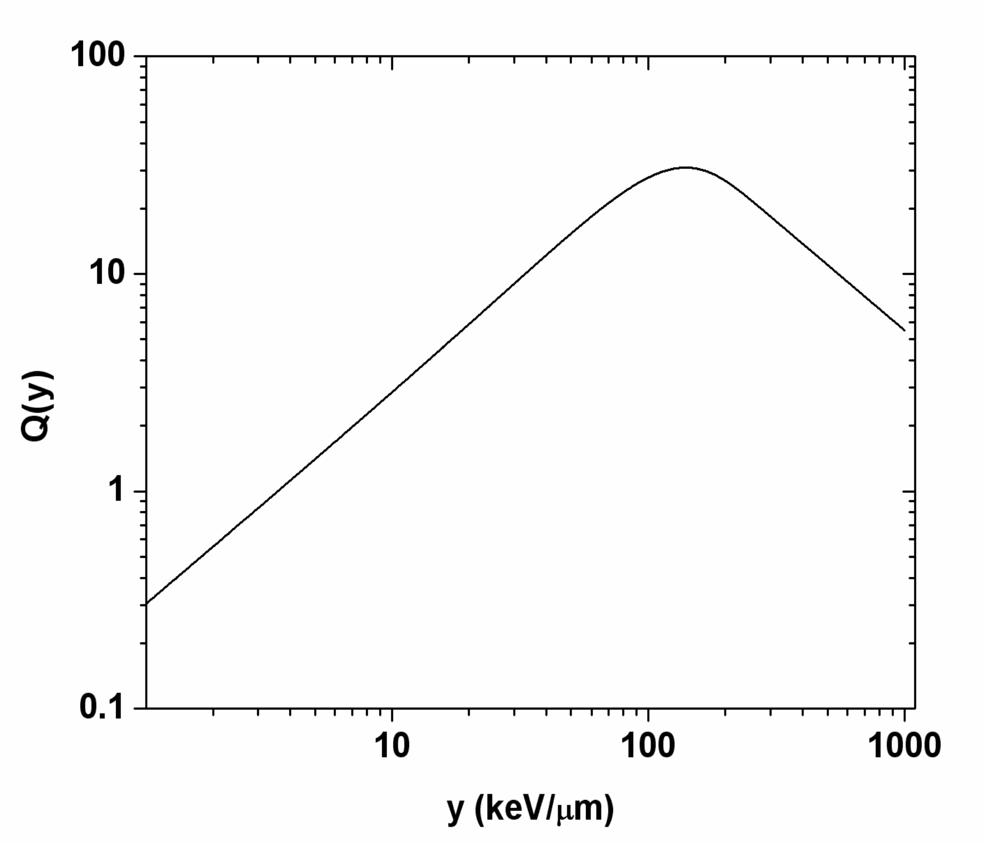
$$d(y) = \frac{yf(y)}{y_f}$$

$$y_f = \int_0^\infty yf(y)dy$$

$$\int_0^\infty d(y)dy = 1$$

Dose Equivalent Determination

- The final step in determining dose equivalent (Sv) is to convolve the dy spectra with a quality spectra Q(y).



$$H = \int_0^\infty Q(y) D(y) dy$$

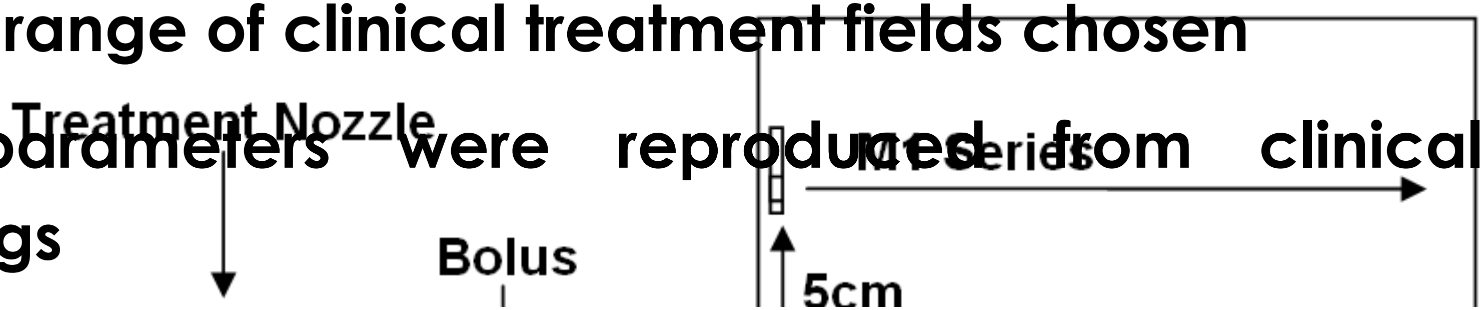
$$\therefore H = \int_0^\infty Q(y) D_{TE} d(y) dy$$

Dose Equivalent Determination

- Advantages include:
  - **Small Size (precision in placement)**
  - **Established Q(y), ICRU 40**
  - **Q(y) changes with lineal energy**
  - **Wide range of lineal energies (1.0-1000keV/μm)**
- Possible errors include:
  - **Noise threshold removing some signal (limit 0.8 keV/μm)**
  - **Q(y) determined in-vitro (artificial case?) not in-vivo (real case?)**
  - **Assumptions in average stopping power conversion**
  - **Secondaries produced within device (I.Cornelius et al, CMRP)**

Clinical Treatment Fields

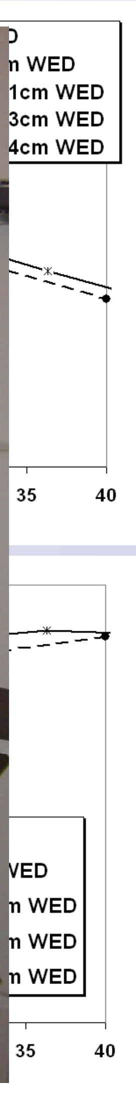
- Wide range of clinical treatment fields chosen
- All parameters were reproduced from clinical settings



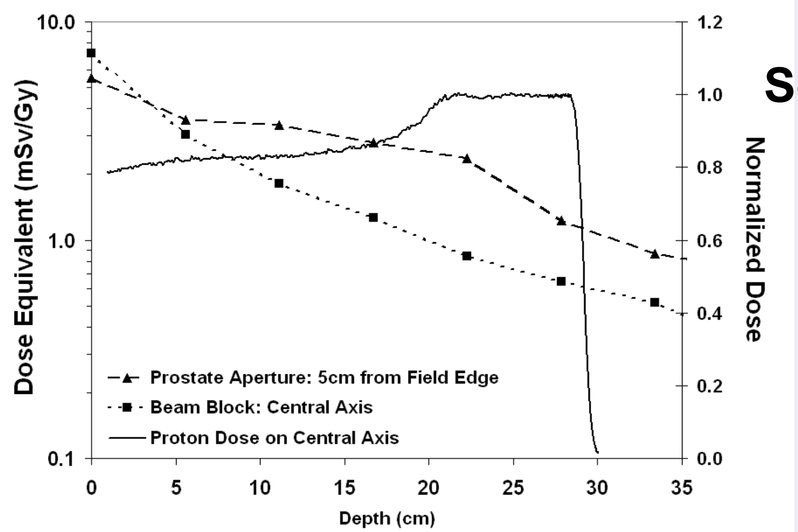
Clinical Disease	Beam Range in Water (cm)	Beam Modulation (cm)	Maximum Field Dimensions (cm)	Pre-collimation field size (cm²)
Prostate	28.8	10.4	6.9, 7.7	184
Medulloblastoma (brain)	15.8	15.9	15, 16.7	547
Medulloblastoma (spine)	9.6	7.4	16.2, 6.5	366
Stereotactic (brain)	18	0	2.0 cm diameter	-
Ocular Melanoma	2.7	2.5	1.1cm diameter	-

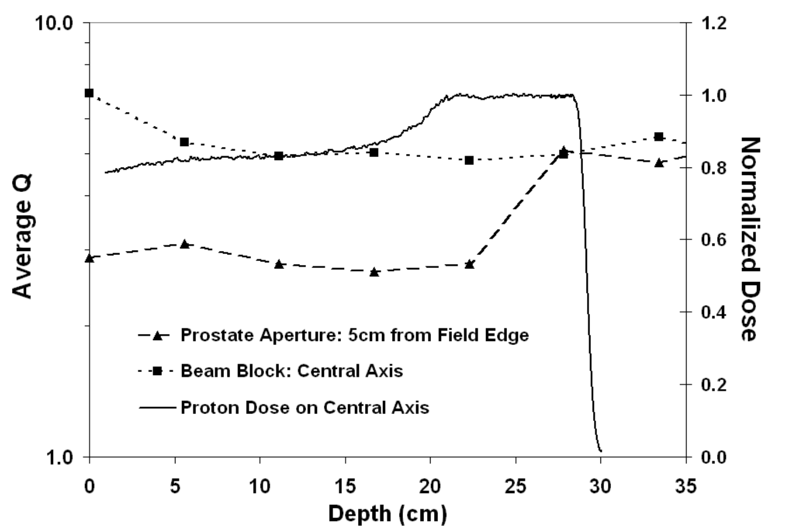
Results

- mSv d
  at late
  field e
- 8.3 mS
- Sharpe
  phant
- Q_{Avg} ir
- Q_{Avg} c
  beam
- H simil
  patien
  surfac
- H high
  axis



Results





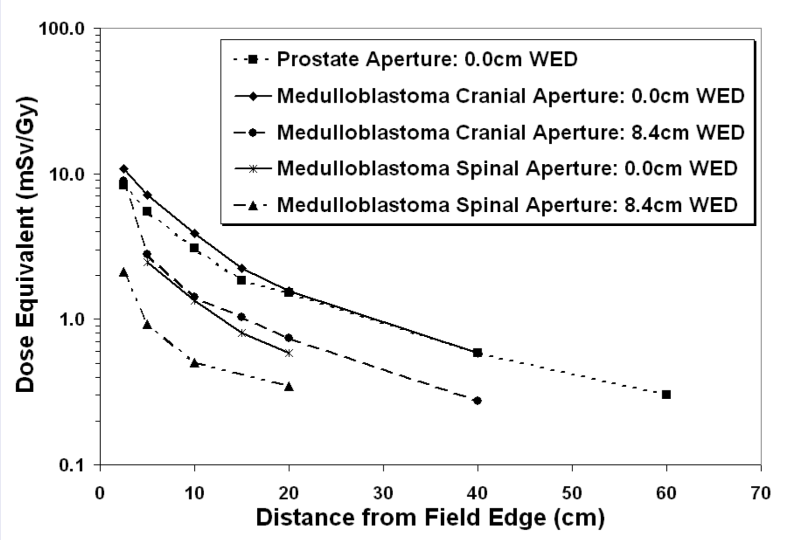
Scanning parallel to the beam at 5cm offset

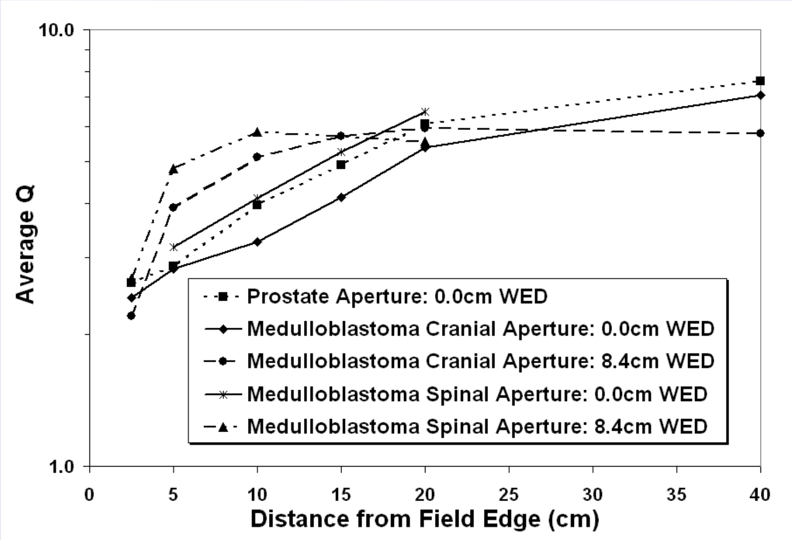
- 5.5 mSv/Gy < $H_{aperture}$ < 0.9 mSv/Gy
- 7.1 mSv/Gy < H_{block} < 0.5 mSv/Gy
- $H_{aperture}$ has a different dependence on depth than H_{block}
- Scattered primary protons affects H and the determination of Q up to 22.3 cm depth (see our poster B.Clasie et al.)
- Downstream of the Bragg peak, difference in H is due to n generated in the phantom

Results:medulloblastoma

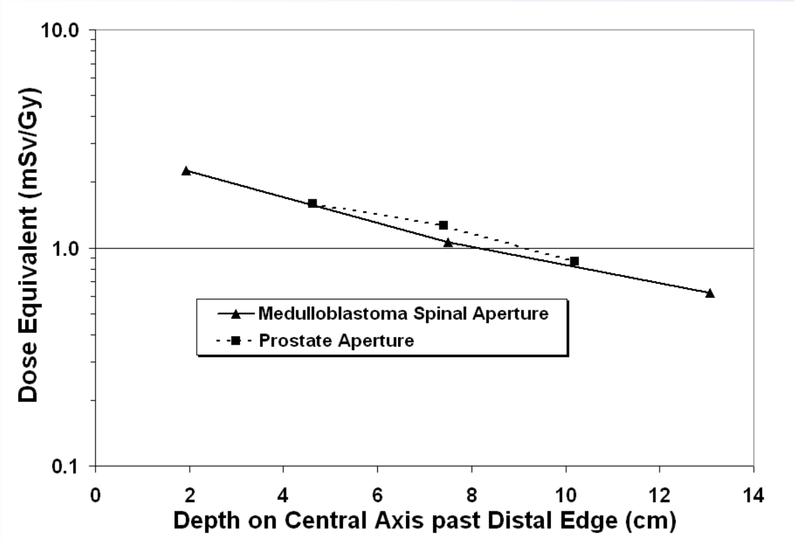
Measurements lateral to the primary field

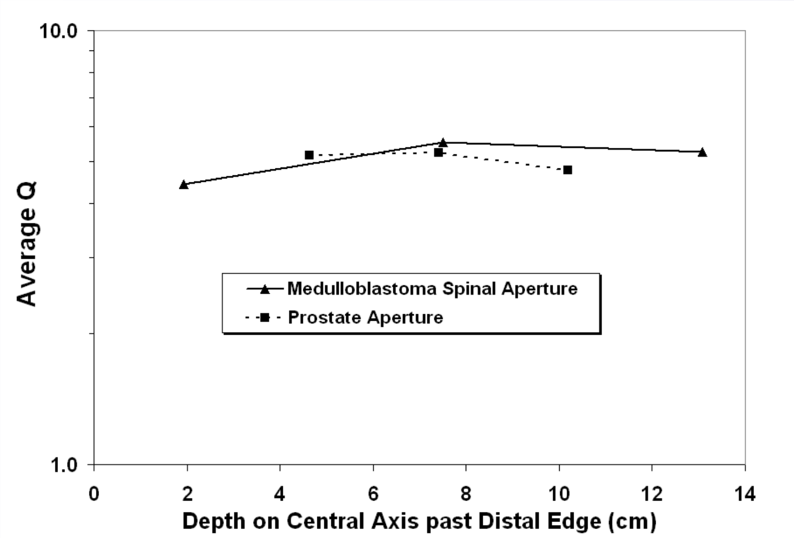
- 10 mSv/Gy < $H_{cranial}$ < 0.6 mSv/Gy at phantom surface
- Cranial medulloblastoma results similar to those for prostate at phantom surface
- In comparison with the prostate cancer field: ↓ Proton Energy ↑ Field Size
- Reducing energy in the spinal case produces less dose equivalent lateral to the primary field
- Q_{Avg} is larger for the spinal case, which indicates that there is less contribution from scattered primary protons





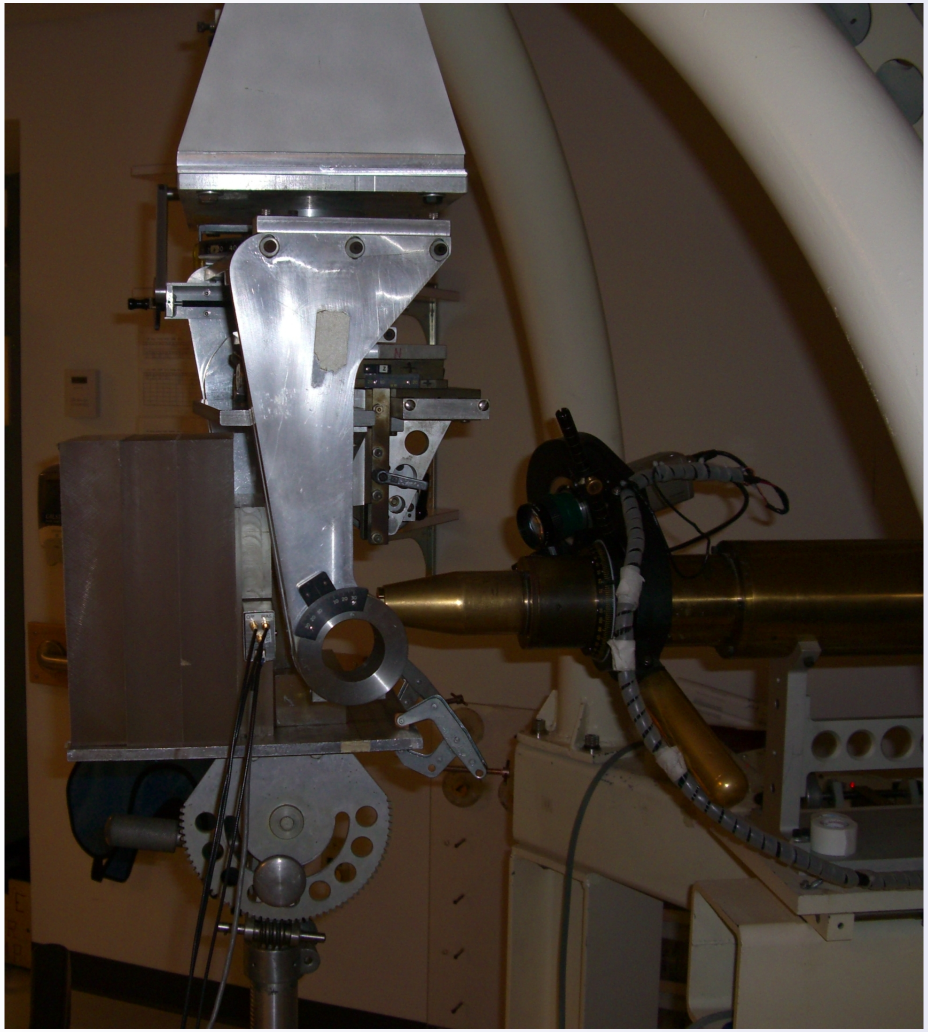
Results: downstream of the Bragg peak





- H and Q_{Avg} on central axis is similar for both treatment configurations
- 2.3 mSv/Gy < H < 0.6 mSv/Gy
- Q_{Avg} constant at 5

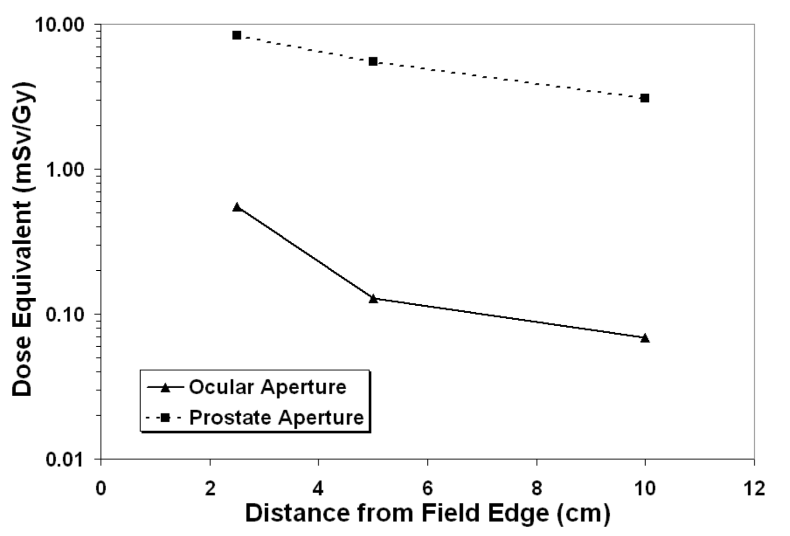
Results: ocular melanoma

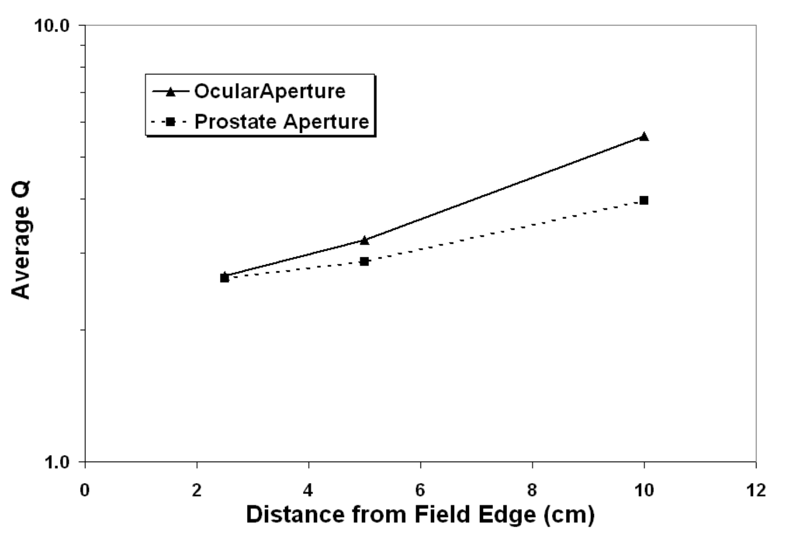


- 27 mm range and 25 mm SOBP
- 1.1 cm diameter field

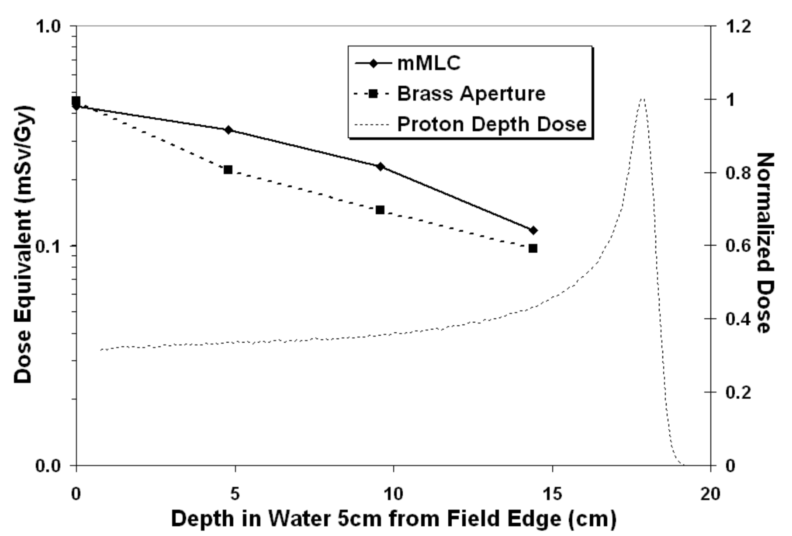
Results: ocular melanoma

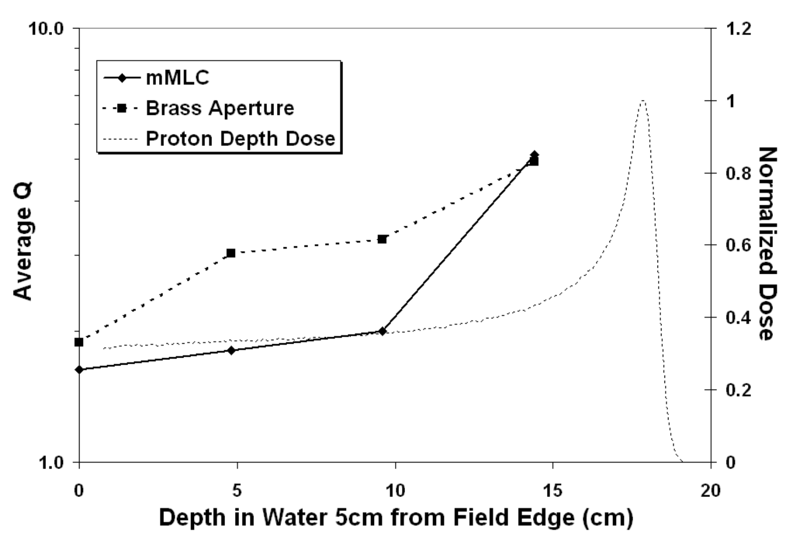
- Greater than order of magnitude difference in H between fields due to lower proton energy
- Q_{Avg} is similar at close to the field and increasing with lateral distance





Results: Stereotactic beam



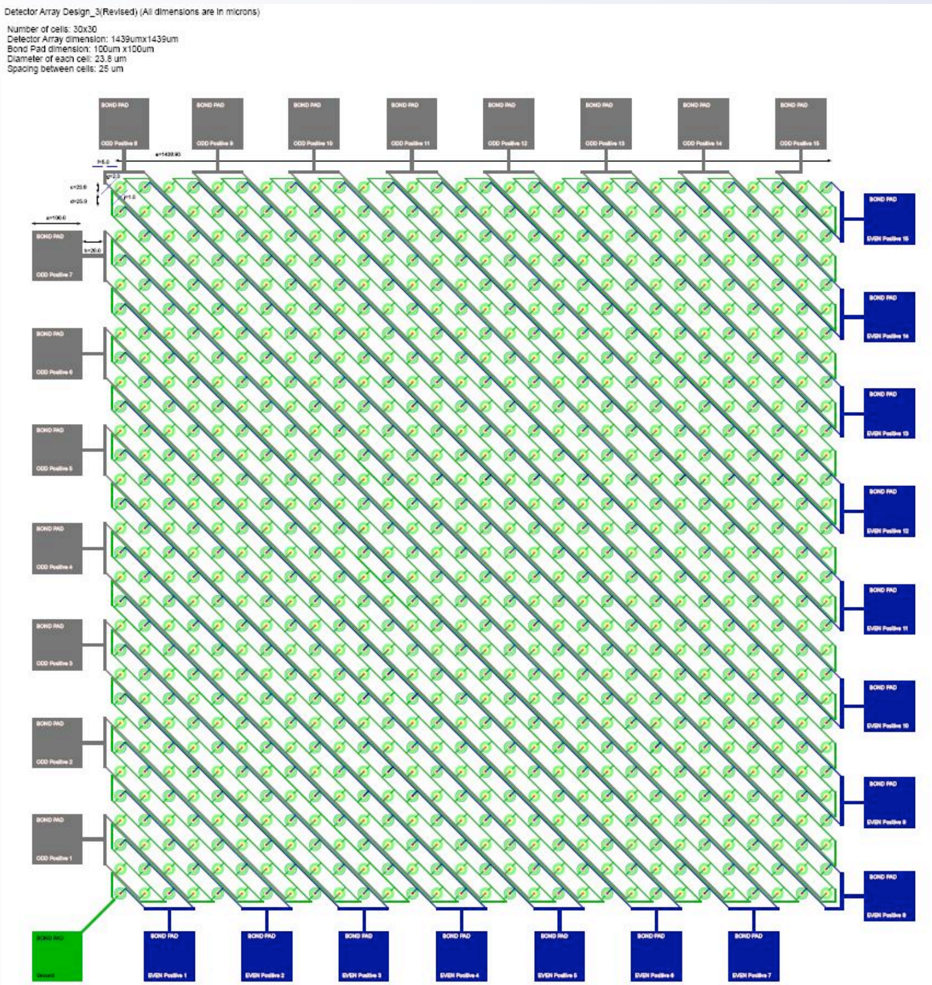


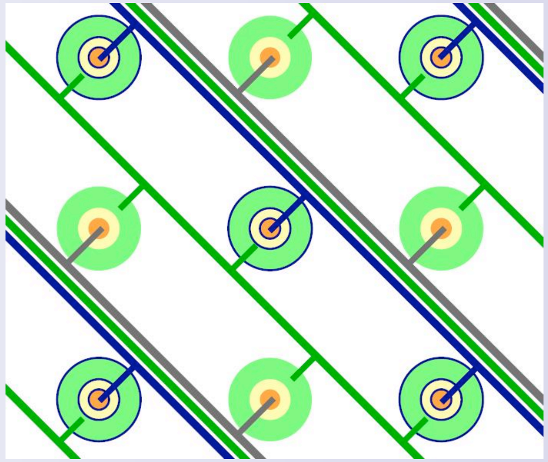
2 cm field diameter in MLC and brass aperture, parallel to the beam at 5cm from the field edge

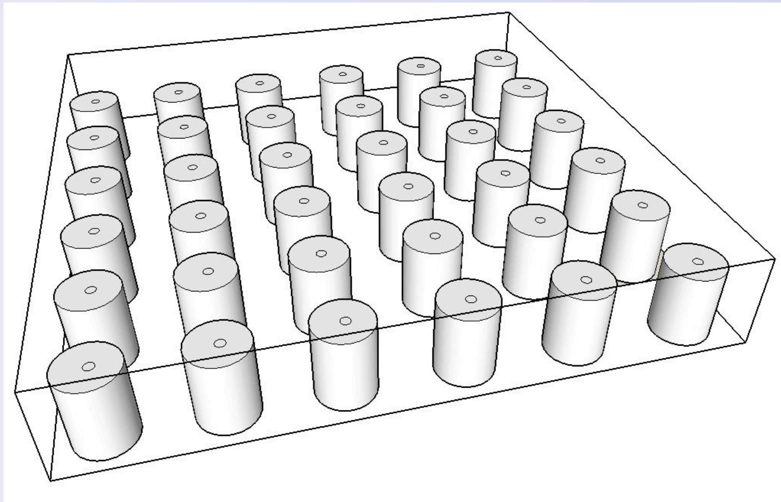
- H higher for the mMLC case by as much as 50%
- Q_{Avg} mMLC is generally lower indicating leakage protons

3D SOI silicon microdosimetry:new design, CMRP

3D silicon cell array: **fabricated at SNFF , UNSW, Australia, Prof A.Dzurak**





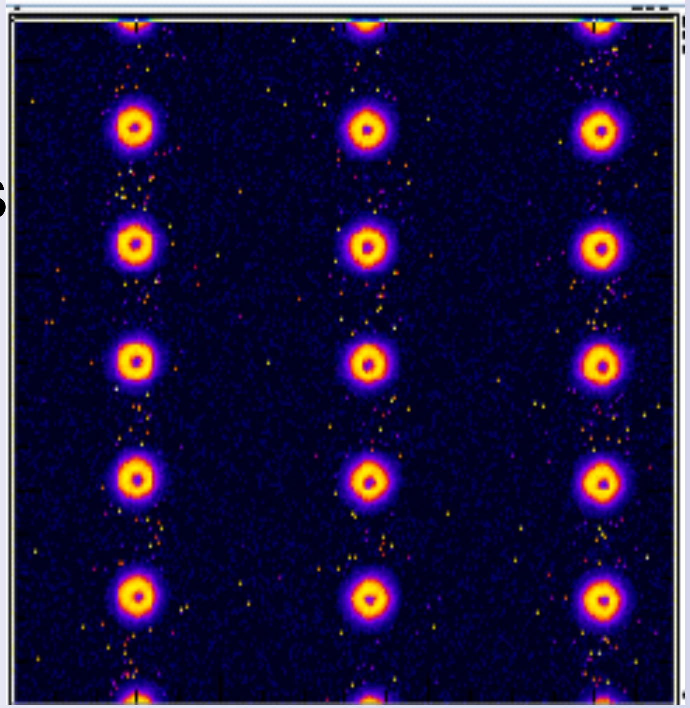


3D SOI silicon microdosimetry:new design, CMRP

Response of new 3D SOI microdosimeter on 1 μm diameter 3 MeV alpha particles scanning microbeam (ANSTO Dr M.Reinhard).

Each cell has sensitive volume with a diameter of 6 μm and pitch 20 μm

Collaboration with ANSTO heavy ions micro beam probe, measurements were done by PhD student Ms Amy Ziebell , CMRP, Uni of Wollongong

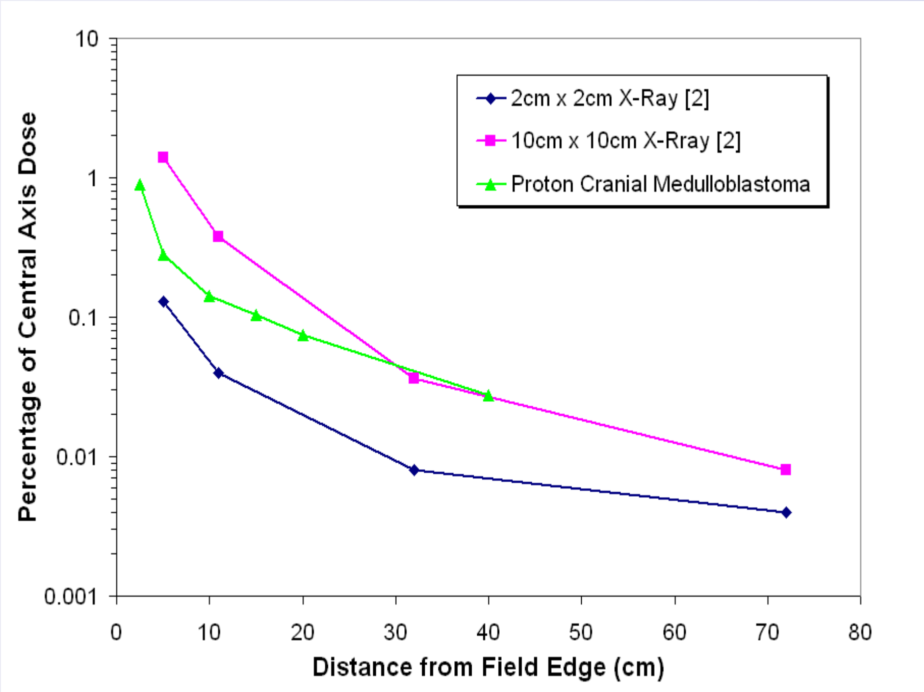


Overall Conclusion

- This work has provided an assessment of dose equivalent for clinical proton therapy configurations
- The results highlight that neutrons are present but are not in great abundance
- External field dose equivalent dose depend on the treatment situation and less with reduced proton energy
- However, the external field dose equivalent is not largely field size dependant as initially hypothesized
- Results obtained are analogous to leakage from MLC's in IMRT or less.

Overall Conclusions

- Leakage radiation for 6MV X-ray measured along patient central axis (depth=10 cm)
- X-Ray data normalised to D_{max} = 1.6 cm
- Proton data for cranial medulloblastoma field (15x17 cm^2) at a WED 8.4 cm
- Proton data normalised to dose at isocenter (i.e. central axis of patient)
- Proton results still consider Q factor
- Proton results a factor of 2-3 lower than that for a 10x10 cm^2 conventional field
- Proton results a comparable to a 10x10 cm^2 conventional field at lateral displacement of 30 cm or greater



[2] E. Klein et al., "Peripheral doses from pediatric IMRT", Med. Phys., 33, 7, 2006, pp. 2525-2531

Are out-of-field doses less of an issue for protons?

Acknowledgements

- Physics Staff at Massachusetts General Hospital, Burn Proton Therapy Centre
- Physics Staff at the Australian Nuclear Science and Technology Organization (ANSTO)